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W. L. Robison

V. E. Noshkin

W. A. Phillips

R. J. Eagle

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LAWRENCE LIVERMORE LABORATORY
University of California • Livermore, California • 94550

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CONTENTS

THE NORTHERN MARSHALL ISLANDS RADIOLOGICAL SURVEY: RADIONUCLIDE CONCENTRATIONS IN FISH AND CLAMS AND ESTIMATED DOSES VIA THE MARINE PATHWAY

ABSTRACT

A radiological survey was conducted in 1978 to assess the concentrations of persistent manmade radionuclides at 12 atolls and 2 islands in the Northern Marshall Islands. The survey consisted, in part, of an aerial radiological reconnaissance to map the external gamma-ray exposure rates over the atolls or islands. As a secondary phase of the survey, shore parties collected terrestrial and marine samples to assess the radiological dose from pertinent food chains to current or potential atoll inhabitants. Over 5000 terrestrial and marine samples were collected for radionuclide analysis from 76 different islands.

Here we present the marine sample collection, processing, and dose assessment methodology as well as the concentration data for ^{90}Sr, ^{137}Cs, ^{238}Pu, $^{239+240}Pu$, and ^{241}Am, and any of the other gamma emitters in fish and clam muscle tissue from the different species collected at all atolls except Bikini and Enewetak. Doses are calculated from the average radionuclide concentrations in fish and clam muscle tissue at each atoll or island assuming an average daily intake of 200 to 10 g, respectively.

The ^{90}Sr concentration in muscle tissue is very low (for the most part undetectable) and there is little difference in the average concentrations from the different fish from different atolls or islands. The $^{239+240}Pu$ concentration in the muscle tissue of all reef species, however, is higher than that in pelagic lagoon fish. In contrast, ^{137}Cs concentrations are lowest in the muscle tissue of the bottom-feeding reef species such as mullet and goatfish and highest in pelagic lagoon fish.

Recent measurements of radionuclide concentrations in fish muscle tissue and other marine dietary items from a variety of national and international sources compared with our analysis of radionuclide concentrations in fish from the Marshall Islands show that the average concentrations in species from the Marshall Islands are comparable to those in fish typically consumed as food in the United States and are generally lower than those in most international marine dietary items.

The whole-body dose rates based on continuous consumption of 200 g/d of fish range from 0.028 mrem/y at Mejit to about 0.1 mrem/y at Rongelap; the bone-marrow dose rates range from 0.029 mrem/y at Mejit to 0.12 mrem/y at Rongelap. The dose commitment, or 30-y integral doses, range from 0.00063 to 0.0022 rem for the whole body and from 0.00065 to 0.0032 rem for the bone marrow.

INTRODUCTION

A radiological survey was conducted from September through November of 1978 to assess the concentrations of persistent manmade radionuclides in the terrestrial and marine environments of 12 atolls and 2 islands in the Northern Marshall Islands. The atolls and islands are shown in Fig. 1 and include Likiep, Taka, Ailinginae, Wotho, Bikar, Ailuk, Rongerik, Ujelang, Utirik, Mejit, Jemo, Rongelap, Bikini, and Enewetak. Concentrations of radionuclides on specific islands of Bikini Atoll have been well documented.[1-4] However, little radiological information is available for the remainder of the atoll or for other atolls that were considered most likely to have received fallout from nuclear tests conducted at the Pacific Proving Grounds between 1946 and 1958.

The survey consisted, in part, of an aerial radiological reconnaissance to map the external gamma-ray exposure rates over the islands of each atoll. The logistic support for the entire survey was designed to accommodate this operation. As a secondary phase of the survey, shore parties collected appropriate terrestrial and marine samples to assess the radiological dose from pertinent food chains to those individuals residing on the atolls, who may in the future reside on some of the presently uninhabited atolls, or who collect food from these atolls.

Over 5000 terrestrial and marine samples were collected for radionuclide analysis from 76 different islands. Soils, vegetation, indigenous animals, and cistern water and groundwater were collected from the islands. Reef and pelagic fish, clams, lagoon water, and sediments were obtained from the lagoons.

A considerable amount of radionuclide concentration data has been generated from the analyses of these samples. Results from different phases of the program will appear in separate reports. In the first report of this series we describe the general operation of the survey, the type and quantity

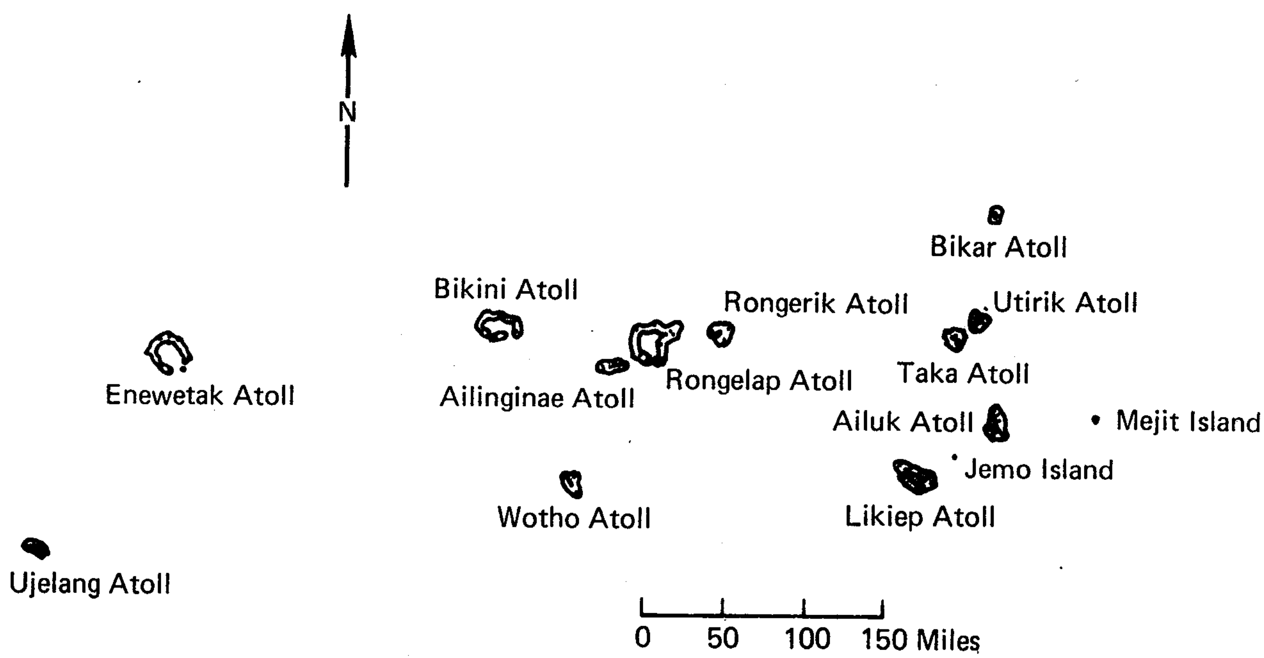

FIG. 1. Atolls and islands of the Northern Marshall Islands radiological survey.

of samples collected, locations sampled, and the methods used to process and analyze the samples.[5] The second report summarizes the radionuclide concentrations in cistern water and groundwater sampled at the atolls and the radiological dose assessment from ingestion of water from atoll supplies.[6] Other reports planned include a description of our analytical quality-control program coordinated by Dr. C. D. Jennings of the Western Oregon State College and radionuclide concentrations in components of the terrestrial environment. Some reports will contain the analytical results and dose assessments for individual atolls while in others the results will be presented for a combination of several atolls. In addition, some results are being summarized for publication in international scientific journals. The final report of this series will provide an assessment of the total dose from the major exposure pathways including external gamma, terrestrial food chains including food products and drinking water, marine food chains, and inhalation.

Here we summarize the concentration data for ^{90}Sr, ^{137}Cs, ^{238}Pu, $^{239+240}$Pu, ^{241}Am, and any of the other gamma emitters in fish and clam muscle tissue dissected from the different species collected at the atolls or islands. More recent results from Bikini and Enewetak Atolls, however, will appear in a separate report. Radiological doses at each atoll or island are calculated from the average radionuclide concentrations in fish and clam muscle tissue assuming an average daily intake of 200 and 10 g, respectively. The data summarized were abstracted from a complete compilation of radionuclide concentrations in the various organs and tissues of fish analyzed.[7]

FISH AND INVERTEBRATE SAMPLE COLLECTION

COLLECTION METHOD

Throw nets were used exclusively to catch reef fish at the atolls. Large pelagic and benthic fish were collected on sport fishing gear using feathered jigs or baited hooks while trolling in the lagoons. Edible clams were collected by hand (free diving) in shallow areas of each lagoon. The fish and clams were returned to the research vessel, segregated by species, placed in plastic bags, and frozen. The samples were shipped frozen to the Lawrence Livermore National Laboratory (LLNL) for storage and eventual processing.

SPECIES COLLECTED, FEEDING HABITS, AND TROPHIC LEVEL RELATIONSHIPS

The principal species collected were selected because they are commonly eaten by the Marshallese; relatively abundant; have different feeding habits; and for some, represent species for which previous radiological data was available at Enewetak and Bikini for comparison. It was not always possible, however, to obtain an adequate number of the same species at every location we sampled because of tides, insufficient time, unavailability of a species, and depletion of a species at inhabited atolls.

Various reef fish were collected. Mullet *Crenimugil crenilabis* and *Neomyxus chaptalii* are herbivorous, detrital feeders that ingest considerable quantities of bottom sediment along with food. Convict surgeonfish *Acanthurus triostegus* are herbivorous browsers feeding on small algal fronds and filamentous algae that grow on reef rock or on the base of dead coral. The unicornfish *Naso lituratus*, also a herbivore, browses on larger seaweed growing on sandy and rocky areas. Rabbitfish *Siganus rostratus* are herbivorous browsers but will occasionally feed on fleshy items found in garbage dump areas. Rudderfish *Kyphosus cinerascens* are strictly herbivorous browsers. All of the above fish belong to the second trophic level.[8] Goatfish *Mulloidichthys samoensis* consume fossorial and other benthic fauna including small clams, crustaceans, other invertebrates, and small fish. This species belongs to the third trophic level.[8] Threadfin *Polydactylus sexfilis* feed strictly on benthonic fauna and also belong to the third trophic level.[8] Parrotfish *Scarus sordidus* are common reef-dwelling, grazing omnivores feeding on live coral heads and occasional algae. Parrotfish are in the fourth trophic level.[8]

Four species of clams, *Tridacna gigas*, *Tridacna squamosa*, *Tridacna crocea*, and *Hippopus hippopus* were collected. These large invertebrates are sessile, filter-feeding mollusks that live on the lagoon bottom and coral reefs.

Larger benthic, midwater, and surface carnivores were also occasionally collected from the lagoons. Grouper *Epinephelus sp.* are benthic carnivores of the third trophic level that feed on small fish and invertebrates.[8] Jacks *Caranx melampygus* and *Elegatis bipinnulatus* (rainbow runner) are fast-swimming carnivores that feed on small fish and squid. *Elegatis bipinnulatus* may occasionally eat swimming crustacea. Snappers *Aprion virescens* (grey snapper) and *Lutjanus bohar* (red snapper) are hovering midwater-to-surface carnivores.

Another snapper *Letherinus kallopterus* (pigfish) is a bottom dweller feeding primarily on benthonic crustacea. Jacks and snappers are in the fourth trophic level.[8] Tuna *Euthynnus affinis* (bonito), *Thunnus albacares*, and *Gymnosarda nuda* and mackerel *Grammatorcynus billineatus* are large, rapid-swimming carnivores feeding on small fish and any other prey of proper size. They represent species of the fifth trophic level.[8]

SAMPLE PROCESSING AND ANALYSIS

The fish samples from each location were numerically counted and partially thawed. The total weight, standard or fork length, and sex of each fish was determined. Each fish was dissected into muscle tissue, bone (cranial and thoracic, vertebrae and ribs, and pelvic and pectoral girdle), skin and scales (fins discarded), stomach contents, liver, and remaining viscera that included large and small intestine with contents, stomach wall, spleen, kidney, and mesenteries. Each separate tissue and organ of the species from the same catch was pooled. Gills were separated from the fish but not analyzed. Our experience prior to 1978 showed the gills were sometimes contaminated with sediment. The gills are not eaten and there could be little academic information gained from their analysis because of the possible contamination. Clams were weighed, measured (total length), and dissected. Adductor muscles, mantle plus siphon, kidney, and remaining viscera that included gills, gonad, stomach, intestine and contents, crystalline style, heart, and nervous system were removed for analysis. Parts from smaller clams such as the *Tridacna crocea* from specific locations were pooled for analysis. For the larger species, analysis was made on individuals. After the wet weight was determined, each fish and clam tissue sample was dried in ovens at 90°C to constant dry weight and dry ashed in muffle furnaces at 450°C for approximately 72 h.

Samples were transferred to aluminum containers, sealed, and analyzed by gamma spectrometry. Gamma-spectrometry measurements were made on all separated samples at LLNL using a variety of Ge (Li)-diode detector systems. Counting times were usually 1000 min or longer for each sample.

A general-purpose computer program, GAMANAL, was used for the data reduction of all generated spectra. The program searches a library of long-lived nuclear explosion products, activation products, and naturally occurring radionuclides to identify radionuclides from any observed photopeak in the gamma spectra. It also generates an upper limit amount of specific radionuclides based on those spectra regions where signals would be seen if the radionuclides were present in detectable quantities. Listed in Table 1 are the detection limit values for various radionuclides based on the average weight of tissue shown for a counting period of 1000 min. For an average-size fish bone sample for example, ^{137}Cs would not have been detected by gamma spectrometry if the concentration was less than 11 pCi/kg dry weight. Except at Bikini and Enewetak, the only radionuclides other than naturally occuring ^{40}K detected in fish and clam muscle tissue by gamma spectrometry were ^{137}Cs and occasionally ^{60}Co. In muscle tissue, all other radionuclides indicated in Table 1 were below the limits of detection by gamma spectrometry. A more complete description of the gamma equipment used, calibration, sensitivity of detection, uncertainties, and methods for setting upper limits is given in Ref. 9.

After gamma analysis the samples were either sent to a contract laboratory or retained at LLNL for radiochemical separations of ^{90}Sr, ^{137}Cs, $^{238,239,240}Pu$, and ^{241}Am. Except for ^{137}Cs, these nuclides cannot be detected by gamma spectrometry and are judged to be of potential significance for dose assessment. The ^{137}Cs was radiochemically separated from muscle tissue and analyzed to confirm the measurements made by gamma spectrometry, which in turn provided a useful interlaboratory calibration for quality control. Separation techniques used at LLNL are published[10] and those used by the contract laboratory are summarized in Ref. 9. A number of duplicate, blank, and standard samples were intermingled with the regular samples analyzed at LLNL and at the contract laboratory. All available quality-control results for the marine samples demonstrated that the analytical performance was extremely good. A full discussion of all the quality control data for the 1978 survey results is in preparation.[11]

DOSE ASSESSMENT METHODOLOGY

An abbreviated description of the dose assessment methodology follows. For a more detailed discussion, the recent report on the radiological reassessment of Enewetak Atoll may be consulted.[12]

BODY WEIGHTS

Data from the Brookhaven National Laboratory[13,14] have been summarized to determine the body weight of the Marshallese people. The average adult male body weight is 72 kg for Bikini, 71 kg for Enewetak, 62 kg for Rongelap, and 70 kg for Utirik. The average, therefore, is very near the 70-kg value of reference man.[15] As a result, we have used 70 kg as the average body weight in our dose calculations. The average body weight for 113 adult females in the Enewetak population is 61 kg. It is 67 kg for 30 Utirik females and 63 kg for 36 Rongelap females.[13]

STRONTIUM-90 METHODOLOGY

Bone-marrow doses and dose rates are calculated in two steps. First, the model of Bennett[16-18] is used to correlate the ^{90}Sr concentrations in diet with that in mineral bone. Second, the dosimetric model developed by Spiers[19] is used to calculate the bone-marrow dose rate from the concentration in mineral bone.

Bennett's empirical model is developed from ^{90}Sr concentrations found in foods and autopsy bone samples from New York and San Francisco. It also includes age-dependent variations that allow us to make dose estimates for children as well as adults.

Using Spiers' model we calculate the dose rate D_o to a small, tissue-filled cavity in bone from the ^{90}Sr concentration in mineral bone. Then from geometrical considerations, the dose rates to the bone marrow D_m and endosteal cells D_s are calculated using the conversion factors $D_m/D_o = 0.315$ and $D_s/D_o = 0.434$, respectively. These factors are quoted by the United Nations Scientific Committee on the Effects of Atomic Radiation.[20] The dose rates are determined directly and not by comparison to radium. Therefore rads are equivalent to rems. Because bone marrow is considered a blood-forming organ (annual dose limit equals 500 mrem/y) and endosteal cells are in an other organ category (annual dose limit equals 1500 mrem/y), the bone marrow is the more sensitive organ in bone for ^{90}Sr (see Ref. 21).

CESIUM-137 METHODOLOGY

For ^{137}Cs and ^{60}Co, the methods of the International Commission on Radiological Protection[22-24] and the National Council on Radiation Protection and Measurements[25] as developed by Killough and Rohwer in their INDOS code[26] are used for the dose calculations. This code is used as published; however, the output is modified to show the body burdens for each year. For ^{137}Cs, which is of major importance in the Marshall Islands, the model consists of two exponential components with half-lives of 2 and 110 d, with 10% of the intake going to the 2-d compartment and 90% to the 110-d compartment. These data are consistent with preliminary data obtained by Brookhaven National Laboratory on the half-life of the long-term compartment in the Marshallese.[27] The average results from 10 Marshallese males showed a mean of 114 d (range: 76 to 178 d) for the long-term compartment. For 21 females the mean value is 83 d (range: 63 to 126 d). The gut transfer coefficient for ^{137}Cs is 1.

TRANSURANIC RADIONUCLIDES METHODOLOGY

For the ingestion pathway, the gut-to-blood transfer coefficient for Pu isotopes is 1×10^{-4} and for ^{241}Am it is 5×10^{-4} (see Ref. 22). The critical organs are bone and liver with 100-y biological half-lives for Pu and Am in bone and 40 y in liver. Of the Pu and Am transferred to the blood, 45% is assumed to reach the bone and 45% is assumed to reach the liver. The remaining 10% is distributed among other organs.

DIETARY INTAKE

The doses reported here are calculated assuming a daily intake of 200 g of fish muscle tissue and 10 g of clam muscle tissue. The 200 g/d intake of fish is an upper limit from two different surveys conducted at various atolls in the Marshall Islands.[12] The average daily intake under normal conditions would be less than 200 g/d. The dose resulting from the daily intake of anything other than 200 g can be easily calculated from the ratio of the newly assumed intake to the 200 g/d intake. If other organs such as fish liver or skin make up a portion of the diet, the resulting doses can be computed from the data in Ref. 7 and the appropriate values for daily intake.

RESULTS

RADIONUCLIDE CONCENTRATIONS IN FISH AND CLAMS

The radionuclide concentration data presented here are abstracted from a detailed report on the radionuclide concentrations in reef and pelagic fish in the Northern Marshall Islands.[7] Summarized in Table 2 is the average muscle radionuclide concentration in various fish from each atoll or island. In Table 3 the average radionuclide concentrations for clams are listed. The average radionuclide concentrations for fish and clams are used in conjunction with the average daily intake of each, the average biological residence times, and the fractional depositions to calculate the maximum annual dose rates and 30-y integral doses.

MAXIMUM ANNUAL DOSE RATES AND 30-Y INTEGRAL DOSES FROM THE MARINE PATHWAY

The maximum annual dose rate for the whole body is defined as the dose rate in that year when the whole-body ingestion dose from ^{137}Cs is a maximum. For bone marrow it is when the bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr is a maximum. Because of the dose buildup from ^{90}Sr and the continuously decreasing dose after the first year for ^{137}Cs, the bone-marrow maximum annual dose rate can occur in a different year than the whole-body maximum annual dose rate.

The maximum annual dose rates at each atoll or island are listed in Table 4. Dose rates are presented for both whole body and bone marrow and both are similar for most of the atolls or islands. The whole-body dose rates range from 0.028 mrem/y at Mejit to about 0.1 mrem/y at Rongelap. The bone-marrow dose rates range from 0.029 mrem/y at Mejit to 0.12 mrem/y at Rongelap.

For perspective, these maximum annual dose rates can be compared to the current United States Federal guidelines for whole body and bone marrow of 500 mrem/y for an individual and 170 mrem/y for a population average.

The dose commitment, or 30-y integral doses, is listed in Tables 5 and 6 for fish and clams respectively. The whole-body doses from fish range from 0.00063 to 0.0022 rem and the bone-marrow doses from 0.00065 to 0.0032 rem. The whole-body doses from clams are on the average about 0.5% of those from fish and, except at Rongelap, the bone-marrow doses are about 10% of those from fish. The doses from clams are calculated using the detection limits as the actual concentrations, so the doses will be less than those listed in Table 6. These 30-y doses can be compared with the United States Federal guideline for whole body of 5 rem in 30 y.

Listed in Table 7 is the contribution of each radionuclide to the 30-y integral dose from fish. The ^{137}Cs is most significant, ^{90}Sr is second in importance, and the transuranics contribute a rather small fraction of the 30-y dose.

In Table 8 the 30-y integral doses are listed for each fish. From this table the dose can be calculated for any combination of marine food products. The predicted doses from combinations of different fish will differ little from the average values previously given.

DISCUSSION

Radionuclide concentrations in fish muscle tissue are summarized in Table 9 from the results in Table 2 and Ref. 7 to show the average levels in all reef and pelagic lagoon fish from each atoll or island. Table 10 shows the average amounts accumulated in muscle tissue of individual reef fish and all pelagic fish from all atolls or islands. Inspection of this and Table 2 shows that concentrations of ^{90}Sr in muscle tissue are very low (undetectable in many of the samples analyzed) and that there is little difference in the average concentrations from the different fish from different atolls or islands. This is not the case for ^{137}Cs and $^{239+240}Pu$.

At all atolls or islands the muscle tissue of all reef fish contain higher concentrations of $^{239+240}Pu$ than the amounts in muscle tissue of pelagic lagoon fish. Further, concentrations of $^{239+240}Pu$ in second trophic level species from Rongelap (mullet and convict surgeonfish) differ significantly from concentrations in these species from the other atolls or islands. The similarities and differences that the results provide with respect to tissue distributions, trophic level relationships, feeding habits, and environmental concentrations of the transuranics has been discussed.[28]

The food chain behavior of ^{137}Cs does not parallel that of $^{239+240}Pu$. Whereas the muscle tissue of mullet are found to have the highest levels of Pu among all species analyzed, ^{137}Cs concentrations are lowest in the muscle tissue of the bottom-feeding fish such as mullet and goatfish. Also unlike $^{239+240}Pu$, highest average concentrations of ^{137}Cs are found in the muscle tissue of the pelagic lagoon fish. A full discussion of the ^{137}Cs concentrations in fish and how these relate to environmental and biological factors is in preparation. It is sufficient to point out here that ^{137}Cs and $^{239+240}Pu$ are accumulated in higher concentrations in some species than in others because of the capacity individual species of fish have to accumulate these radionuclides from the environment. Therefore to minimize ingestion of ^{137}Cs (presently the largest contributor to the small doses from the marine food chain), species of bottom-feeding fish should make up a larger fraction of the marine diet.

COMPARISON OF FISH AND INVERTEBRATE RADIONUCLIDE CONCENTRATIONS TO THOSE OF UNITED STATES AND OTHER MARINE FOOD PRODUCTS

Recent measurements of radionuclide concentrations in fish muscle tissue and other marine dietary items from a variety of national and international sources are summarized in Tables 11 and 12 respectively. Several obvious generalizations can be made by comparing these independent results to our analysis of fish radionuclide concentrations at the Marshall Islands. The average concentrations of ^{90}Sr in the muscle tissue of any species from the atolls or islands fall within the range observed in fresh fish typically found in the United States and Japanese markets.

The ^{90}Sr is approximately two to three times less in fish from the atolls or islands than the average ^{90}Sr concentration found in fish products imported to the United States for consumption.

If the sources for canned marine foods imported to Likiep, Wotho, Ailuk, Ujelang, Utirik, Mejit, and Rongelap are those also supplying the United States, it is obvious that the ^{90}Sr concentrations in present-day imported fish exceeds the average concentration in the muscle tissue of all fish indigenous to these atolls and islands. The ^{137}Cs concentrations shown in Tables 2 and 10 are also within the range of levels associated with United States marine dietary products and are significantly less than concentrations in many commerical fish consumed in the United Kingdom. Except at Rongelap, concentrations of ^{137}Cs in mullet are generally lower than the concentration presently detected in the mullet from the east coast of the United States. Except for the second trophic-level fish from Rongelap, $^{239+240}Pu$ levels in fish are also comparable to those concentrations in similar types of species consumed in the United States. The Pu concentrations in mullet and convict surgeonfish from Rongelap are lower than average levels in pelagic fish consumed in the United Kingdom. The Pu, however, presently contributes only a small fraction of the dose from ingestion of marine food products.

DOSE COMPARISONS

The estimated, maximum annual radionuclide dose rates from the consumption of fish are about 0.01% of the 500 mrem/y Federal guideline for most atolls and islands and about 0.02% for Rongelap. The 30-y integral doses range from about 0.01 to 0.06% of the Federal 30-y guideline of 5 rem. The estimated doses from the consumption of clams is only a very small fraction of that from the intake of fish (on the average, less than 0.5% for the whole body and less than 10% for bone marrow). The clams contribute this very small fraction of the dose in the marine pathway even though detection limit values were used as the actual concentration. In fact, the concentration in clams will be less than these values. Therefore, the actual doses from ingestion of clams will be less than those shown in Table 6 and would actually contribute an even smaller fraction of the dose relative to fish.

The doses estimated for the various radionuclides for the marine pathway must be viewed with the likely source of each radionuclide in mind. The doses listed here are based on the currently observed radionuclide concentrations at the atolls and islands. The Cs and Sr concentrations in fish from the atolls and islands are similar to those observed in fish from other locations around the world in which the concentrations are derived from global fallout. Therefore, doses calculated for Cs and Sr reflect concentrations of these nuclides in the water column. These concentrations can increase if any type of global atmospheric testing occurs because the primary source of these two radionuclides is from global fallout; any residual activity from the 1950 tests contributes only a small fraction of the activity that is presently associated with the muscle tissue of fish.

The radionuclide doses are calculated using the current radionuclide concentrations and assuming that they are removed by only physical (i.e., radiological) decay. However, the residence time of Cs and Sr in the upper oceanic water columns is less than their 30-y half-life. Therefore the doses, in absence of any further testing, are probably overestimated.

The Pu and Am concentrations are higher at the atolls and islands than expected from global fallout, but the levels in the muscle tissue of certain species of reef fish are only slightly higher than fallout levels. A source of these radionuclides, in addition to global fallout, is residual material in the sediments and coral that was deposited during the test years. However, the estimated doses from Pu and Am are a very small fraction of the estimated total doses via the marine pathway, which in turn are only a small fraction of the current guidelines.

APPENDIX: TABLES

TABLE 1. Average radionuclide detection limits by gamma-ray spectrometry for 1000 min count.

Marine sample type	Average sample weight, g	Average radionuclide detection limit (pCi/g dry wt)							
		^{60}Co	^{101}Rh	^{102m}Rh	^{125}Sb	^{137}Cs	^{155}Eu	^{207}Bi	^{241}Am
Muscle	400	0.008	0.003	0.004	0.01	0.004	0.008	0.004	0.013
Skin	300	0.008	0.003	0.005	0.013	0.005	0.01	0.005	0.017
Viscera	150	0.015	0.007	0.01	0.027	0.011	0.02	0.01	0.033
Bone	150	0.015	0.007	0.01	0.027	0.011	0.02	0.02	0.033
Stomach contents	15	0.15	0.07	0.1	0.27	0.11	0.2	0.1	0.33
Liver	10	0.23	0.1	0.15	0.4	0.16	0.3	0.15	0.5

TABLE 2. Concentrations of anthropogenic radionuclides in fish muscle tissue collected from the Northern Marshall Islands during 1978.

Atoll or island and total number of fish	Fish and number	Radionuclide concentration in muscle tissue (pCi/kg wet wt) ^{90}Sr Range	^{90}Sr Mean	^{137}Cs Range	^{137}Cs Mean	^{238}Pu Range	^{238}Pu Mean	$^{239+240}Pu$ Range	$^{239+240}Pu$ Mean	^{241}Am Range	^{241}Am Mean
Likiep	Mullet (26)	0.3-<1	0.7	6.6-7.4	7	--	<0.005	0.03-0.04	0.035	<0.003-0.02	0.01
(294)	Surgeonfish[a] (98)	1-<3	1.9	7-23	16	--	<0.04	0.03-0.07	0.06	--	<0.02
	Rabbitfish (25)	--	<0.1	--	4.7	--	<0.01	--	<0.01	--	<0.02
	Rudderfish (25)	--	<0.3	--	11.4	--	0.02	--	0.04	--	0.007
	Goatfish (109)	<0.2-0.7	0.4	5-7.6	6.2	--	<0.05	<0.003-0.02	0.013	--	<0.005
	Parrotfish (23)	--	<0.6	10-14	12.2	<0.004-0.07	0.04	0.01-1.4	0.08	--	<0.05
Taka	Mullet (70)	0.3-0.6	0.5	3.3-3.4	3.3	<0.005-0.02	0.009	0.13-0.19	0.15	<0.006-0.03	0.02
(132)	Surgeonfish (59)	0.3-0.8	0.5	11-17	14	--	<0.03	0.05-0.12	0.08	<0.006-0.04	0.02
	Large carnivores[b] (3)	--	0.2	19-34	28	--	<0.01	<0.004-0.007	0.005	--	<0.003
Ailinginae	Mullet (36)	--	<0.6	5.8-13.9	9.3	<0.007-0.07	0.03	0.14-0.24	0.2	<0.007-0.02	0.015
(283)	Surgeonfish (142)	0.2-1.1	0.8	19-27	23	<0.01-0.09	0.04	0.05-0.19	0.12	<0.1-0.08	0.04
	Goatfish (92)	0.2-0.4	0.3	6.9-7.2	7	<0.01-<0.03	<0.02	0.01-0.3	0.02	--	<0.01
	Parrotfish (9)	--	0.2	--	18	--	0.02	--	0.07	--	<0.002
	Large carnivores (4)	<0.2-<0.5	<0.3	14-35	22	<0.006-<0.02	<0.009	<0.008-0.02	0.01	<0.002-0.02	<0.008
Wotho	Mullet (95)	--	<0.4	8.1-10	8	0.005-0.012	0.009	0.04-0.13	0.1	0.01-0.03	0.02
(300)	Surgeonfish (130)	--	<0.2	20-22	21	--	<0.003	--	0.04	--	<0.002
	Goatfish (65)	<0.1-<0.4	<0.2	6.6-7.2	6.9	<0.009-<0.02	<0.01	<0.003-<0.01	<0.006	<0.007-<0.009	--
	Parrotfish (8)	--	<0.5	13-16	15	--	<0.01	--	0.02	--	<0.02
	Large carnivores (2)	--	0.2	18-22	20	<0.001-<0.008	<0.004	<0.003-<0.006	<0.004	0.002-0.004	0.003
Bikar	Mullet (70)	--	0.15	5.7-6.2	6	--	0.008	--	0.016	--	lost
(144)	Surgeonfish (62)	<0.2-<1	<0.5	22-25	23	<0.004-0.04	0.02	<0.004-0.04	0.02	<0.006-0.06	0.03
	Parrotfish (8)	<0.8-1	0.9	21-24	23	<0.008-0.03	0.01	<0.008-0.05	0.03	<0.01-0.03	0.02
	Large carnivores (4)	<0.1-0.6	0.4	24-28	26	<0.001-<0.003	<0.002	0.009-0.012	0.01	--	<0.01
Ailuk	Mullet (32)	--	<0.4	5.9-7.7	7	0.005-0.05	0.02	--	0.06	--	<0.01
(173)	Surgeonfish (41)	<0.7-<0.1	<0.8	11-20	15	<0.01-0.05	<0.03	<0.03-0.08	0.05	<0.008-0.01	<0.01
	Goatfish (99)	<0.1-<0.5	<0.3	5.7-7.2	6	--	<0.009	--	<0.01	<0.001-0.1	<0.005
	Large carnivores (1)	--	<0.7	--	16	--	<0.02	--	<0.02	--	0.005

TABLE 2. (Continued.)

Atoll or island and total number of fish	Fish and number	Radionuclide concentration in muscle tissue (pCi/kg wet wt)									
		^{90}Sr		^{137}Cs		^{238}Pu		$^{239+240}Pu$		^{241}Am	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Rongerik (290)	Mullet (35)	--	<0.3	5.3-7.4	6.4	--	<0.01	0.07-0.3	0.18	--	<0.004
	Surgeonfish (221)	<0.2-0.6	0.36	14-20	17.5	<0.002-0.01	<0.006	0.01-0.15	0.09	<0.005-0.02	0.01
	Goatfish (19)	--	0.8	--	8.3	--	<0.01	--	0.024	--	0.015
	Threadfin (6)	--	0.45	--	16.3	--	<0.003	--	<0.003	--	<0.008
	Parrotfish (2)	--	<0.6	--	15.4	--	<0.02	--	<0.007	--	<0.01
	Large carnivores (7)	--	<0.3	14-40	25	<0.003-0.02	<0.01	0.005-<0.01	0.01	--	<0.006
Ujelang (164)	Surgeonfish (20)	--	0.2	--	5.9	--	<0.002	--	<0.002	--	<0.009
	Goatfish (57)	--	<0.16	5.6-6.9	6.3	--	<0.005	--	<0.003	--	<0.004
	Large carnivores (87)	--	<0.03	16-24	20	--	<0.005	<0.006-0.04	0.02	--	<0.01
Utirik (113)	Surgeonfish (3)	--	<1.5	--	23	--	<0.2	--	0.4	--	<0.6
	Rudderfish (23)	--	<0.3	--	3.9	--	<0.02	--	<0.02	--	0.01
	Goatfish (76)	--	lost	--	6.2	--	<0.001	--	<0.001	--	<0.001
	Threadfin (7)	--	<0.3	--	15	--	<0.02	--	<0.01	--	<0.01
	Parrotfish (1)	--	<1.4	--	--	--	<0.06	--	0.06	--	<0.02
	Large carnivores (3)	--	<0.4	15-24	20	--	<0.01	--	<0.01	--	<0.01
Mejit (70)	Rudderfish (70)	--	--	--	6.8	--	<0.001	--	<0.002	--	--
Jemo (99)	Surgeonfish (71)	--	<2	14-21	18	--	<0.03	0.04-0.13	0.09	--	<0.08
	Threadfin (28)	--	<0.07	--	15	--	<0.003	--	0.002	--	<0.002
Rongelap[c] (605)	Mullet (74)	0.5-2	0.9	16-133	42	<0.003-0.04	0.013	0.03-1.3	0.72	0.01-0.12	0.06
	Surgeonfish (276)	<0.2-1.1	0.7	18-55	33	<0.003-0.04	0.02	0.06-0.47	0.32	<0.01-0.13	0.06
	Goatfish (233)	0.3-2.8	1	7-8.5	7.6	<0.007-0.02	0.02	0.008-0.04	0.024	<0.003-0.02	0.01
	Parrotfish (15)	--	<0.1	--	16.3	--	0.01	--	0.15	--	<0.008
	Large carnivores (7)	<0.2-<0.6	<0.3	12-62	28	0.007-<0.03	0.02	<0.004-0.009	0.006	<0.001-<0.02	--

[a]Convict surgeonfish.

[b]Large carnivores include grouper, jack, snapper, tuna, and mackerel.

[c]Concentrations of ^{60}Co in muscle tissue were also determined in pCi/kg wet wt for species at Rongelap Atoll. For mullet the range is <1.3-9.5 and the mean is 3. For convict surgeonfish the range is <1.3-10 and the mean is 3. For parrotfish the range is <1.3-2 and the mean is 1.5.

TABLE 3. Concentrations of anthropogenic radionuclides in the muscle and mantle of clams collected from the Northern Marshall Islands during 1978.

Atoll and island	Species	Tissue	Radionuclide concentration (pCi/kg wet wt)[a]					
			^{90}Sr	^{137}Cs	^{238}Pu	$^{239+240}Pu$	^{241}Am	^{60}Co
Likiep (L-50)	Hippopus hippopus	Muscle	<1.4	<0.9	<0.03	<0.03	<0.06	<1.3
		Mantle	0.9 (24)	<2	<0.03	0.17 (40)	<0.03	<1.3
Likiep (L-31)	Tridacna squamosa	Muscle	<1.4	<0.7	<0.15	0.33 (37)	<0.05	<5
		Mantle	1.1 (50)	<3	<0.04	0.18 (45)	<0.04	23 (14)
Taka (H-1)	Hippopus hippopus	Muscle	<5	<1	<0.09	<0.09	<0.2	<4
		Mantle	2.2 (40)	<0.3	<0.07	0.09 (80)	<0.07	<2
Taka (H-4)	Hippopus hippopus	Muscle	<3	<2	0.2 (50)	0.4 (34)	<0.3	<7
		Mantle	<2	<2	<0.05	0.37 (27)	0.27 (35)	14 (21)
Taka (H-4)	Tridacna gigas	Muscle	<2	<2	<0.09	<0.09	<0.09	<5
		Mantle	0.9 (50)	<0.9	<0.05	0.13 (37)	<0.05	<2
Ailinginae (C-15)	Hippopus hippopus	Mantle	<5	--	<0.4	4.5 (18)	1.2 (29)	<1
Ailinginae (C-24)	Tridacna squamosa	Muscle	<1	<0.8	<0.03	0.33 (34)	lost	<1
		Mantle	<2	<1	0.09 (50)	2 (10)	0.5 (25)	<1
Ailinginae (C-24)	Hippopus hippopus	Muscle	1 (50)	<0.3	0.19 (75)	0.39 (50)	<0.2	<1
		Mantle	<0.8	<0.3	<0.05	1.1 (11)	0.42 (37)	17 (25)
Wotho (M-1)	Hippopus hippopus	Muscle	<5	--	<0.01	0.09 (39)	0.1 (50)	<3
		Mantle	<0.7	<0.1	<0.12	0.24 (75)	0.21 (50)	<3
Wotho (M-17)	Hippopus hippopus	Muscle	<1.8	<0.5	<0.4	<0.1	<0.03	<3
		Mantle	<0.6	0.5 (60)	0.12 (70)	0.12 (30)	0.2 (80)	<3
Bikar (D-1)	Hippopus hippopus	Muscle	<2	2.6 (38)	<0.07	0.13 (60)	0.7 (70)	<3
		Mantle	<4	<0.4	0.05 (60)	0.28 (20)	0.1 (45)	<3
Bikar (D-1)	Tridacna crocea	All[b]	4 (40)	<0.7	0.17 (16)	1.77 (16)	0.38 (45)	<3
Ailuk (lagoon)	Tridacna squamosa	Muscle	<1.2	<1	<0.02	0.1 (50)	<0.03	<3
		Mantle	<1.3	<1.2	<0.02	0.19 (30)	0.2 (30)	<4
Ailuk (A-11)	Tridacna crocea	All[b]	4 (60)	<1.7	<0.07	0.5 (36)	<0.2	<3
Rongerik (G-1)	Tridacna gigas	Muscle	<2	9.1 (13)	<0.09	0.34 (43)	0.4 (40)	<3
		Mantle	<0.7	0.5 (58)	<0.02	<0.02	<0.06	<3

TABLE 3. (Continued.)

Atoll and island	Species	Tissue	Radionuclide concentration (pCi/kg wet wt)[a]					
			^{90}Sr	^{137}Cs	^{238}Pu	$^{239+240}Pu$	^{241}Am	^{60}Co
Rongerik (G-1)	*Hippopus hippopus*	Muscle	5 (50)	<1	<0.04	<0.07	<0.04	<3
		Mantle	1.3 (60)	--	<0.06	0.36 (27)	0.1 (50)	<3
Rongerik (G-6)	*Hippopus hippopus*	Muscle	3.9 (40)	2.7 (40)	<0.03	0.36 (34)	0.2 (90)	<3
		Mantle	<0.7	<0.4	<0.2	0.7 (13)	lost	<3
Ujelang (J-18)	*Tridacna crocea*	Muscle	<6	--	<0.4	0.6 (65)	0.49 (40)	--
Ujelang (J-22)	*Tridacna crocea*	Muscle	<2	1.2 (60)	<0.01	<0.5	0.2 (60)	<3
		Mantle	<2	0.8 (40)	<0.006	0.42 (14)	0.19 (28)	<3
Utirik (I-1)	*Tridacna crocea*	Muscle	--	<6	--	--	--	--
		Mantle	<3	<2	0.3 (80)	0.7 (36)	lost	9.6 (25)
Utirik (I-1)	*Tridacna crocea*	Muscle	<3	1 (90)	<0.04	0.44 (34)	<0.06	<3
		Mantle	<3	1.3 (50)	0.22 (29)	1.1 (13)	0.27 (30)	<3
Utirik (I-1)	*Hippopus hippopus*	Muscle	<2	<0.2	<0.04	<0.08	<0.06	<3
		Mantle	2 (40)	<0.5	0.11 (50)	0.14 (40)	<0.03	<3
Rongelap (F-13)	*Hippopus hippopus*	Muscle	9.7 (60)	<3	<0.2	3.4 (2)	1.1 (29)	<3
		Mantle	8.1 (50)	2 (40)	0.15 (37)	31.1 (4)	7.1 (7)	<3
Rongelap (F-13)	*Hippopus hippopus*	Muscle	3.4 (50)	1.8 (60)	0.39 (31)	2.5 (11)	1.4 (16)	<3
		Mantle	6.9 (11)	1.2 (40)	0.06 (60)	12.6 (5)	4.6 (6)	<3
Rongelap (F-33)	*Tridacna squamosa*	Muscle	<1.4	2.1 (35)	0.08 (70)	0.66 (23)	0.5 (20)	<3
		Mantle	<1.7	<0.5	<0.1	4.2 (8)	2.3 (8)	17 (9)

[a]The percent standard deviations of the counting error are in parentheses.

[b]Muscle and mantle.

TABLE 4. Maximum annual dose rate in mrem/y of ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, and ^{241}Am for a 200 g/d intake of fish at the Northern Marshall Islands.[a]

Atoll or island	Maximum annual dose rate (mrem/y) Whole body	Bone marrow[b]
Likiep	0.038	0.06
Taka	0.06	0.069
Ailinginae	0.063	0.073
Wotho	0.055	0.06
Bikar	0.079	0.089
Ailuk	0.044	0.055
Rongerik	0.059	0.07
Ujelang	0.044	0.048
Utirik	0.055	0.074
Mejit	0.028	0.029
Jemo	0.067	0.09
Rongelap	0.099	0.12

[a]Average of all fish. Those values below the detection limit were excluded.
[b]Includes the dose from Pu and Am that is calculated as the total bone dose rather than the bone-marrow dose.

TABLE 5. The 30-y integral dose in rem of ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, and ^{241}Am for a 200 g/d intake of fish at the Northern Marshall Islands.[a]

Atoll or island	The 30-y integral dose (rem)	
	Whole body	Bone marrow[b]
Likiep	0.00082	0.0016
Taka	0.0013	0.0018
Ailinginae	0.0014	0.0019
Wotho	0.0013	0.0015
Bikar	0.0018	0.0022
Ailuk	0.00098	0.0014
Rongerik	0.0013	0.0018
Ujelang	0.00098	0.0012
Utirik	0.0013	0.002
Mejit	0.00063	0.00065
Jemo	0.0015	0.0024
Rongelap	0.0022	0.0032

[a] Average of all fish. Those values below the detection limit were excluded.

[b] Includes the dose from Pu and Am that is calculated as the total bone dose rather than the bone-marrow dose.

TABLE 6. The 30-y integral dose in rem of ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, and ^{241}Am from the consumption of 10 g/d of clams at the Northern Marshall Islands.

Atoll	The 30-y integral dose (rem)		Percent of dose relative to fish	
	Whole body	Bone marrow	Whole body	Bone marrow
Likiep	0.000008	0.000065	1	4
Taka	0.0000071	0.00017	0.69	9.4
Ailinginae	0.0000025	0.00023	0.18	12
Wotho	0.0000017	0.0001	0.13	7.3
Bikar	0.0000042	0.00022	0.23	10
Ailuk	0.0000063	0.00015	0.6	10
Rongerik	0.0000089	0.00012	0.7	6.7
Ujelang	0.0000043	0.00018	0.4	15
Utirik	0.0000084	0.00015	0.7	7.5
Rongelap	0.0000071	0.0015	0.1	47

TABLE 7. The 30-y integral dose in rem for each radionuclide for an intake of 200 g/d of fish at the Northern Marshall Islands.[a]

	The 30-y integral dose (rem)				
		^{137}Cs		$^{239+240}Pu$	^{241}Am
Atoll	^{90}Sr in bone marrow	Whole body	Bone marrow	in total bone[b]	in total bone[b]
Likiep	0.00062	0.00085	0.00085	0.000046	0.000052
Taka	0.00025	0.0013	0.0013	0.00015	0.0001
Ailinginae	0.00027	0.0014	0.0014	0.000085	0.00014
Wotho	0.00012	0.0013	0.0013	0.000055	0.000062
Bikar	0.0003	0.0018	0.0018	0.000019	0.00013
Ailuk	0.00034	0.00098	0.00098	0.000055	0.000026
Rongerik	0.00031	0.0013	0.0013	0.000065	0.000067
Ujelang	0.00012	0.00098	0.00098	0.00002	0.000041
Utirik	0.0005	0.0013	0.0013	0.00023	0.000052
Rongelap	0.00053	0.0022	0.0022	0.00024	0.00022

[a]Average of all fish. Those values below the detection limit were excluded.
[b]Bone-marrow doses would be about one-fourth of these values.

TABLE 8. The 30-y integral dose in rem of ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, and ^{241}Am for a 200 g/d intake of fish for each species collected at the Northern Marshall Islands.[a]

	The 30-y integral dose (rem)															
	Mullet		Convict surgeonfish		Rabbitfish		Rudderfish		Goatfish		Threadfin		Parrotfish		Large carnivores[b]	
Atoll or island	Whole body	Bone marrow	Whole body	Bone marrow	Whole body	Bone marrow	Whole body	Bone marrow	Whole body	Bone marrow	Whole body	Bone marrow	Whole body	Bone marrow	Whole body	Bone marrow
Likiep	0.00063	0.0011	0.0014	0.0028	0.00042	0.0006	0.00097	0.0012	0.00054	0.00082	--	--	0.0011	0.0018	--	--
Taka	0.00029	0.00086	0.0013	0.0017	--	--	--	--	--	--	--	--	--	--	0.0025	0.0026
Ailinginae	0.00084	0.0015	0.0021	0.0029	--	--	--	--	0.00063	0.00088	--	--	0.0016	0.0018	0.002	0.0022
Wotho	0.00071	0.0012	0.0019	0.0021	--	--	--	--	0.00063	0.0008	--	--	0.0013	0.0018	0.0018	0.0019
Bikar	0.00054	0.00065	0.0021	0.0025	--	--	--	--	--	--	--	--	0.0021	0.0027	0.0023	0.0026
Ailuk	0.00063	0.00099	0.0013	0.0019	--	--	--	--	0.00054	0.00076	--	--	--	--	0.0014	0.0019
Rongerik	0.00058	0.00097	0.0016	0.0019	--	--	--	--	0.00076	0.0014	0.0015	0.0018	0.0015	0.0018	0.0022	0.0025
Ujelang	--	--	0.00054	--	--	--	--	--	0.00071	0.00058	--	--	0.0007	--	0.0018	0.0019
Utirik	--	--	0.0021	0.0037	--	--	--	--	0.00054	0.00054	0.0013	0.0016	--	0.001	0.0018	0.0021
Mejit	--	--	--	--	--	--	0.00063	0.00063	--	--	--	--	--	--	--	--
Jemo	--	--	0.0016	0.0034	--	--	--	--	--	--	0.0013	0.0014	--	--	--	--
Rongelap	0.0038	0.0053	0.0029	0.004	--	--	--	--	0.00067	0.0014	--	--	0.0015	0.017	0.0025	0.0027

[a] Detection limits are considered to be actual concentrations.

[b] Includes grouper, jack, snapper, tuna, and mackerel.

TABLE 9. Summary of average radionuclide concentrations in muscle tissue from fish collected at each atoll or island during the Northern Marshall Islands radiological survey.[a]

Atoll or island	Radionuclide concentration (pCi/kg wet wt)							
	All reef fish[b]				All pelagic lagoon fish[c]			
	^{90}Sr	^{137}Cs	$^{239+240}Pu$	^{241}Am	^{90}Sr	^{137}Cs	$^{239+240}Pu$	^{241}Am
Likiep	0.7±0.6	11±4	0.04±0.03	0.02±0.02	--	--	--	--
Taka	0.5	9±7	0.12±0.05	0.02	<0.2	28	0.005	<0.003
Ailinginae	0.5±0.3	14±7	0.1±0.07	0.02±0.02	<0.3	22	0.01	<0.008
Wotho	<0.3	13±6	0.04±0.04	0.01±0.01	0.2	20	<0.004	0.003
Bikar	0.5±0.4	17±9	0.04±0.04	0.01±0.01	0.4	26	0.01	<0.01
Ailuk	<0.5	9±5	0.04±0.03	<0.01	<0.7	16	<0.02	0.005
Rongerik	0.5±0.3	13±5	0.07±0.07	0.009±0.004	<0.3	25	0.014	<0.006
Ujelang	0.2±0.1	6±1	<0.003	<0.005	<0.3	20	0.02	<0.01
Mejit	--	7	<0.002	--	--	--	--	--
Jemo	<1	16±2	0.04±0.04	<0.08	--	--	--	--
Rongelap	0.7±0.4	24±15	0.3±0.3	0.03±0.03	<0.3	28	0.006	0.006

[a]Detection limit values for individual samples are treated as positive numbers for averaging unless all concentrations were detection limits, in which case the maximum detection limit is listed as the less-than number.

[b]Includes mullet, convict surgeonfish, rabbitfish, rudderfish, goatfish, threadfin, and parrotfish.

[c]Includes grouper, jack, rainbow runner, snapper, tuna, bonito, and mackerel.

TABLE 10. Summary of average radionuclide concentrations in fish muscle tissue of individual reef fish and all pelagic lagoon fish collected at the Northern Marshall Islands.

	Radionuclide concentration (pCi/kg wet wt)				
	^{90}Sr	^{137}Cs	$^{239+240}Pu$		
Fish	All atolls	All atolls	Rongelap	Remaining atolls	All atolls
Mullet	0.5±0.3	10±8	0.7±0.51	0.11±0.08	--
Convict surgeonfish	0.8±0.6	22±11	0.31±0.22	0.09±0.08	--
Goatfish	0.5±0.6	7±2	--	--	0.021±0.026
Parrotfish	0.5±0.4	16±4	--	--	0.056±0.058
Remaining reef fish	0.3±0.2	10±5	--	--	0.014±0.014
Pelagic lagoon fish	0.3±0.2	23±8	--	--	0.011±0.008

TABLE 11. Concentrations of radionuclides in different United States fresh, commercial marine foods.

Marine food and location	Year	Radionuclide concentration (pCi/kg wet wt)				Reference number
		^{90}Sr	^{137}Cs	$^{239+240}Pu$	^{241}Am	
Fish fillets						
New York City	1974	--	--	0.0017	--	29
New York City	1978	0.6	--	--	--	30
New York City	1979	0.6	--	--	--	31
San Francisco	1978	0.3	--	--	--	30
San Francisco	1979	0.3	--	--	--	31
Chicago[a]	1978	--	20±5	--	--	32 and 33
Imported[b]	1971-77	2	24	--	--	34
San Diego albacore	1977	--	30	--	--	35
San Francisco snapper	1977	--	17±2	0.008±0.003	--	36
Oregon turbot	1979	<0.4	15	0.022	<0.02	--[c]
North Carolina mullet	1979	--	9	<0.07	--	--[c]
San Francisco squid	1980	--	--	0.06	--	--[c]
Shellfish						
New York City	1974	--	--	0.04	--	29
New York City	1978	1.4	--	--	--	30
New York City	1979	1.5	--	--	--	31
San Francisco	1978	0.5	--	--	--	30
San Francisco	1979	0.8	--	--	--	31
East and gulf coast invertebrates[d]	1976	--	1.3	0.09	0.02	37
West coast invertebrates	1976-77	--	1.6	0.15	0.36	37

[a] April and October catches averaged.

[b] Includes fresh, frozen, and canned fish.

[c] Unpublished results from LLNL.

[d] Includes *Mytilus edulis*, *Crassostrea virginica*, and *Ostrea equestris*.

TABLE 12. Concentrations of radionuclides in marine fish caught outside of the United States.

Marine food	Location	Year	Radionuclide concentration (pCi/kg wet wt) ^{90}Sr	^{137}Cs	$^{239+240}Pu$	^{241}Am	Reference number
Plaice, cod, flounder, herring, and mackerel	Whitehaven, Fleetwood, and Morecambe Bay, United Kingdom	1977	--	9100	1.1	0.9	38
Plaice and cod	Irish Republic	1977	--	2600	--	--	38
Plaice, cod, herring, and sand eel	Northern North Sea	1977	--	120	--	--	38
Flounder and flatfish	Tokai, Japan	1971-75	0.9	7.5	0.099	--	39
Sebastes malsuburai, *Scombrops boops*, *Hyperoglyphe japonica*, *Paracaesio caeruleus*, and *Beryx splendens*	Japan	1978-79	--	19	--	--	40
Paralichthys olivaceus, *Lotella maximoniczi*, *Lateolabrax japonicus*, *Katsuwonus pelamis*, and *Argyrosomus argentatus*	Japan	1978-79	--	18	--	--	40

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